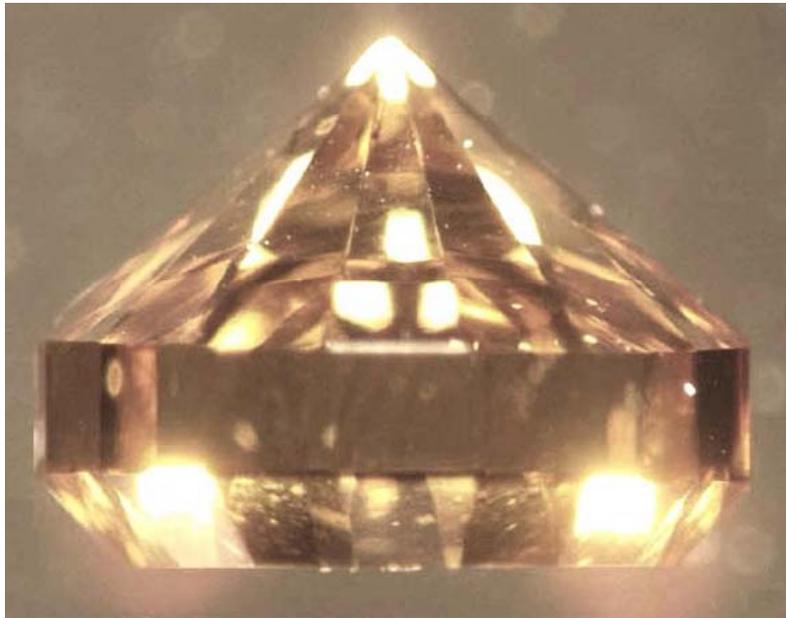


Nanomanufacturing Industry in the U.S. – Survey 2003



Final Report to National Science Foundation

May 12, 2004

NSF Award DMI -0305091/Prepared by:
National Center for Manufacturing Sciences



Background

The National Center for Manufacturing Sciences (NCMS) was requested by the National Science Foundation (NSF) in early 2003 to undertake a study of efforts within the conventional manufacturing industry on key trends, issues and activities towards development and commercialization of nanomanufacturing technologies. The results were regarded as useful input to the Grand Challenge in Manufacturing at the Nanoscale.

Dr. Manish Mehta, Director of Collaboration Programs at NCMS served as Principal Investigator.

The study was performed under NSF Award: DMI-0305091, with oversight of Dr. Mihail C. Roco, Senior Advisor for Nanotechnology to NSF and Chairman U.S. NSET, and Dr. Julie Chen, NSF Nanomanufacturing Program Manager.

On the Cover:

Diamond windows of a new technology—a diamond single crystal measuring 2.5 mm high (about 1/3 carat) grown in one day—courtesy Dr. Russell J. Hemley, Geophysical Laboratory, Carnegie Institution of Washington. The process used is a special high-pressure microwave plasma chemical vapor deposition technology that produces coherent homoepitaxial growth of single crystal diamond on a single crystal substrate at very high growth rates. Nanoscale modeling is being used to understand the general CVD process and to extend the approach for nanomanufacturing.

About NCMS:

NCMS is a not-for-profit organization, based in Ann Arbor, MI, and a premier provider of collaborative research, information, knowledge and expertise to the North American manufacturing and defense community. Backed by 150 corporate members, NCMS has spearheaded numerous advancements – in advanced materials, alternative energy, electronics, high performance machining, process control, rapid prototyping/manufacturing, enterprise integration, information technology, and environmental conscientiousness – all focused on enhancing the nation's manufacturing competitiveness in the global economy.

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EXECUTIVE SUMMARY

The National Science Foundation (NSF) recently awarded a grant to the National Center for Manufacturing Sciences (NCMS) to evaluate the interest of industry in manufacturing at the nanoscale. NCMS reports here the nation's first aggregate survey of the emerging nanomanufacturing industry.

The survey was taken by over 80 strategic and technology executives in small, medium and large manufacturing corporations, both start-ups and established organizations, and provides insight on how companies pursuing diverse nanomanufacturing markets view the development of nanotechnologies and perceive risks.

Nanotechnologies are being developed and commercialized by a broad range of players and targeted for multiple markets – Electronics/Semiconductors, Coatings, Devices/Sensors, Automotive, Display Materials, Biotech/Biomedical, and Polymers. Small companies dominate specialty products development.

Nearly half of the respondents considered nanomanufacturing as an urgent area for development, and nearly two-thirds of the industry executives felt their business and markets are experiencing significant change, however, 82% were dissatisfied with how their organizations are coping with change.

Over 50% of the organizations have insufficient internal capacity to pursue developments in nanomanufacturing, and nearly 75% of the respondents expressed varying degrees of inadequacy in infrastructure for undertaking nanomanufacturing developments. Over three-quarters (80%) employ less than 30 development staff and 50% have less than 10 staff.

The majority of companies surveyed are involved in some form of collaborative technology development to address resource shortfalls by leveraging, many with academic partners. Nearly everyone favored a government role in promoting the nanomanufacturing industry, mainly by incentives.

Of the 15 identified barriers to nanomanufacturing, the executives ranked these as the top challenges:

- Public perception that nanotech products are far from commercialization
- Insufficient investment capital
- Intellectual property issues and impediments
- Process scalability
- High cost of processing
- Societal benefits of nanotechnology not yet recognized

Much collaborative work remains amongst academia, corporations, investors and the government to accelerate the development and commercialization of nanotechnologies in order to exploit the immense economic opportunities and address the risks.

1. INTRODUCTION

Survey Objective:

The objective of the NCMS-NSF Nanomanufacturing Industry Survey was to determine and assess some key aggregate trends and concerns about nanomanufacturing in the United States manufacturing industry, via a targeted questionnaire, and to identify some success stories or in-progress efforts in applications of nanomanufacturing nearing commercialization.

It was anticipated that the survey would reveal an important “snapshot” of interest, attitudes/perceptions, strategic activities and plans of conventional manufacturing industry towards manufacturing at the nanoscale.

Potential Uses of Survey Information:

- The at-a-glance survey results provide a useful snapshot of the industry profile for promoting nanomanufacturing technology awareness within the government, general industry and the public.
- Enable benchmarking within the industry and comparisons across markets, geographical regions, products and technology segments.
- Develop focused technology awareness and training programs and curricula for future events and industry briefings on nanotechnology.
- Provide feedback for the government’s program of the National Nanotechnology Initiative (NNI) and Nanomanufacturing Program at NSF.

2. METHODOLOGY

NCMS drafted the interactive survey questionnaire and launched the on-line survey during the period April – September 2003, initially soliciting its corporate membership of nearly 150 small, large and medium organizations through its monthly periodicals and newsletter publications. Next, NCMS targeted strategic and technology planning executives within its manufacturing industry partners, numbering nearly 6,000 individuals from industry, government and academia, including about 88 companies known to be focused on nanotechnology developments. The solicitations invited executives involved in nanomanufacturing technology developments to respond to the on-line survey questionnaire accessible at the NCMS corporate website (www.ncms.org). Respondents were also encouraged to share anecdotal information or key concerns, as well as success stories of their developments.

A total of 81 industry respondents from small, medium and large corporations took the survey, including 22 who identified themselves in the nanotechnology industry.

Survey raw data sets were processed and analyzed using Microsoft Excel. Survey statistics, trends and responses were illustrated for ease of interpretation.

3. DISCUSSION OF RESULTS

The NCMS-NSF Nanomanufacturing Industry Survey results indicate that early commercialization developments of nanotechnology have been in catalysis, coatings, electronic devices, sensors, medical diagnostics and high performance materials.

Selected Comments on Barriers to Nanomanufacturing

- *“Need much better nanofabrication and manufacturing technologies and techniques i.e., directed self-assembly, synergy of top-down and bottom-up, etc.”*
- *“Novel high-volume and 3D nanomanufacturing technology is missing.”*
- *“Nanotechnology hype is hurting real progress. We don’t need another dot.bomb cycle.”*
- *“Lack of knowledge—we can’t sell anything we can’t make and we can’t make anything yet.”*
- *“Commercialization of new products, especially those which have the potential to make disruptive advances in other fields.”*
- *“Insufficient understanding to enable prediction of needed properties and how to achieve them.”*
- *“Inadequate characterization capability.”*
- *“For large-scale use in the automotive industry, suppliers must first and clearly demonstrate the value proposition for nanotechnology products – better performance at affordable cost and higher reliability.”*

The main barrier perceived by survey respondents is the widespread perception amongst the public that nanotechnology is far from reaching the market – this barrier points to the need for more public awareness efforts in de-mystifying nanotechnology, its societal benefits, and relationship to economic growth. Other key industry barriers include the lack of investment capital for more rapid growth and commercialization scale-up across multiple end-user markets, intellectual property issues, the high processing cost, and poor process scalability.

Of particular note, two key factors, (1) foreign competition and (2) environmental and safety concerns were not indicated by respondents as higher importance barriers. It is believed that this “anomaly” is due to the majority of respondents being small businesses and start-ups that have not yet reached significant sales volumes and product manufacturing using nanotechnology, that would necessitate making significant investments in environmental compliance technologies. The majority of the respondents felt that the U.S. is a leader in nanomanufacturing, perhaps due to its established use in the semiconductor industry.

The survey findings present the industry's collective opinion that the government needs to play a major role in addressing the barriers by promoting R&D collaborations, providing access to capital intensive R&D facilities, and sharing advances and awareness within the larger industry and the public, thereby assuring that the enormous potential benefits of nanotechnology may be realized quickly.

The goals and applications of many nanotechnology developments are unique and too long term for the fragmented industry and the market to take a leadership role. Due to the highly interdisciplinary and phenomenological nature, the development of nanotechnology products and processes requires creating collaborative teams of chemists, physicists, biotechnologists, engineers and entrepreneurs to tackle the technology and manufacturing challenges, and the cooperating funding agencies will need to be organized to leverage and foster this teamwork.

Only a small percentage of survey respondents indicated they have adequate access to specialized R&D infrastructure facilities. This issue points to the need for widespread and simplified access to the enabling world-class research and production capabilities, training and facilities infrastructure, all of which must be in place for the emerging industry to rapidly capitalize on innovations in nanotechnology. The investment would help accelerate the National Nanomanufacturing Industry base, critical for economic development and workforce growth.

Several respondents recommended that follow-up industry "pulse" surveys be conducted and broadly disseminated on a regular basis as the technology evolves and matures in North America.

4. CONCLUSION

The emerging national nanomanufacturing industry perceives itself to be in an era of rapid technological and market change of global proportions. Strategies to achieve significant compression of lead time, and the enabling resources for commercialization are needed to maintain the United States' leadership in nanotechnology products and processes, and for the industry to be regarded as an important source of future manufacturing and high technology jobs. Parallel development of research and commercial products, and leveraging of synergy among industry, university, and government partners are required, along with effective assessment and feedback mechanisms as the industry evolves and matures. Best practices advanced by the industry will help improve collaboration, problem-solving, and consensus-building, and unite entrepreneurs, nanotechnologists and policy makers on common terms and visions for the industry, thereby accelerating innovation.

NCMS-NSF Nanomanufacturing Industry Survey Results

The NSF commissioned the NCMS to conduct the nation's first industry "pulse" survey amongst conventional manufacturing organizations to identify trends and concerns for addressing in the Grand Challenge on Manufacturing at the Nanoscale. The survey invitation was delivered electronically during April – September 2003 to over 6,000 manufacturing executives in the metalworking and polymer processing industries, including 88 targeted nanotechnology companies. The results presented below are for responses of 81 senior level executives with technology strategy and R&D responsibility at small to large corporations.

1. Which industries are you involved in?

Nanotechnology developments are being targeted for use in diverse industries by the researchers. Top seven end uses are:

- 35% for Electronics
- 33% for Coatings
- 32% for Devices and Sensors
- 19% for Automotive Applications
- 18% for Raw Materials Supply
- 15% for Biotechnology/Biomedical
- 13% for Polymers and Petrochemicals

2. How fast is your industry/market changing?

Nearly two-thirds (63%) of executives feel that their business and market(s) are changing rapidly, thereby impacting their organization's strategy. Less than 10% felt that change is slow in their business.

3. How is your company/organization changing its strategy to accommodate nanomanufacturing technology developments?

Only 16% of respondents felt their organizations are coping well with strategy changes (e.g., technology/product portfolio, investments, market focus, etc.), and only 2% felt they are coping poorly; the majority (82%) appear to be struggling with developing and implementing strategies for nanotechnology products.

4. What is your company/organization's capacity for pursuing development of nanomanufacturing technologies?

Over 50% of respondents felt their organizations do not possess sufficient internal capacity to pursue nanomanufacturing developments. In cross-correlating the data, it appeared that larger companies and start-up companies with alliances with universities fared better and have greater capacity for taking risks in nanotechnology-focused investments.

5. Is your company/organization's infrastructure (e.g., lab space, processing equipment, test and diagnostics capability, etc.) adequate for nanomanufacturing?

- 18% felt infrastructure is sufficient
- 9% felt infrastructure is insufficient
- 75% felt critical infrastructure and access are lacking for nanomanufacturing developments

6. Rate your company/organization's urgency for commercializing new nanomanufacturing advances into product.

- 48% feel their organizations have placed high priority on commercialization
- 9% feel their organizations have placed low priority
- 43% feel organizations feel commercialization is placed on medium priority

Companies that are start-ups (often with venture capital) tended to place high priority on commercialization of nanomanufacturing developments.

7. Is your company/organization developing nanotechnology products internally or via external collaborations (with customers, suppliers, academia, National Labs, trade groups, etc.)?

- 6% – Mostly collaborative development
- 3% – Strictly internal efforts
- 91% – Combination of internal and collaborative work

8. How many staff members are involved in your company/organization's nanomanufacturing activities?

- 42% – Less than 10 staff
- 40% – 11-30 staff
- 12% – 31-50 staff
- 6% – Over 50 staff

Two companies stated their nanotech development staffing exceeds 100 persons.

9. When does your company/organization expect to introduce commercial products incorporating nanotechnologies?

- 28% – Already marketing nanotechnology products
- 15% – Will commercialize within 1 year
- 26% – Will commercialize within 3 years
- 20% – Expect to commercialize within 3-5 years
- 11% – Commercialization will take longer than 5 years

10. What types of nanomanufacturing technology products are being pursued in your organization?

A broad range and functionality of nanotechnology products have or are reaching commercialization. Top five product categories are:

- 20% – Coatings
- 15% – Sensors
- 15% – Other (catalysis products, electronic devices, optical displays, high performance materials)
- 8% – Polymers for specialty applications
- 7% – Film and membrane products

19% executives chose not to provide this information

11. What is your opinion of the government's role in promoting nanomanufacturing technologies?

- 2% feel the government should assume all risks in nanotechnology developments
- 51% feel government should invest heavily and offer incentives to industry
- 32% feel government should only support pre-commercial nanomanufacturing activities
- 13% feel that industry should lead developments and government provide funds
- 2% feel government involvement is not needed in nanotechnologies

12. What are the key challenges facing the U.S. nanomanufacturing industry?

Key challenges have to do with the widespread industry and public perception that nanotech is far from reaching the market – this points to the need for more public awareness on nanotechnology, its societal benefits, and relationship to economic growth. Other barriers include intellectual property, process cost, scalability and complexity. Of particular note, foreign competition was not considered an important barrier, nor was environmental and safety concerns indicated as important barriers.

Top six industry concerns indicated:

- 15% feel nanotechnology products are a long way from commercialization
- 14% feel there is insufficient investment capital for nanotechnology
- 12% feel intellectual property issues impede commercialization progress
- 11% feel process scalability is an area of challenge
- 11% feel the cost of processing is too high
- 9% feel societal benefits of nanotechnology are not yet recognized.

**Presentation at National Nanotechnology Initiative Conference
Manufacturing Workshop
March 31 – April 2, 2004 in Washington, DC**

Survey of Nanomanufacturing Industry in the U.S.

**Commissioned by
National Science Foundation (NSF)**

NNI Conference, March 31, 2004

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Acknowledgements

- **National Science Foundation**
 - Division of Design, Manufacturing and Industrial Innovation (DMII) Award # DMI-0305091
 - Dr. Mihail C. Roco, Senior Advisor
 - Dr Julie Chen, Program Director
 - Dr. Haris C. Doumanidis, Program Director
- **NCMS**
 - MIS & Knowledge Solutions Staff
- **Survey Respondents**



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This is NCMS...

...not-for-profit technology, information and education consortium providing value-added products and services that enable **collaboration** and learning among manufacturers

...**cross-industry** manufacturing R&D and program management services



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Value of Survey

- **“Pulse” of U.S. Nanomanufacturing Industry**
- **Assess Key Trends, Strategies, Plans, Concerns**
- **Develop Aggregate Industry Statistics**
- **Profile Early Successes in Commercialization**
- **Program Evaluation as the Industry Evolves**



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Survey Methodology

- Electronic Questionnaire to
NCMS Members (150+ organizations)
+ 6,000 U.S. Metalworking & Polymer Executives
+ 88 U.S. based Nanotechnology Companies
- Total Responses = 81



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Survey Results

**Strong Views,
Many Misconceptions!**



Nanomanufacturing Markets

Nanotechnology is being developed by diverse players & targeted for multiple markets –

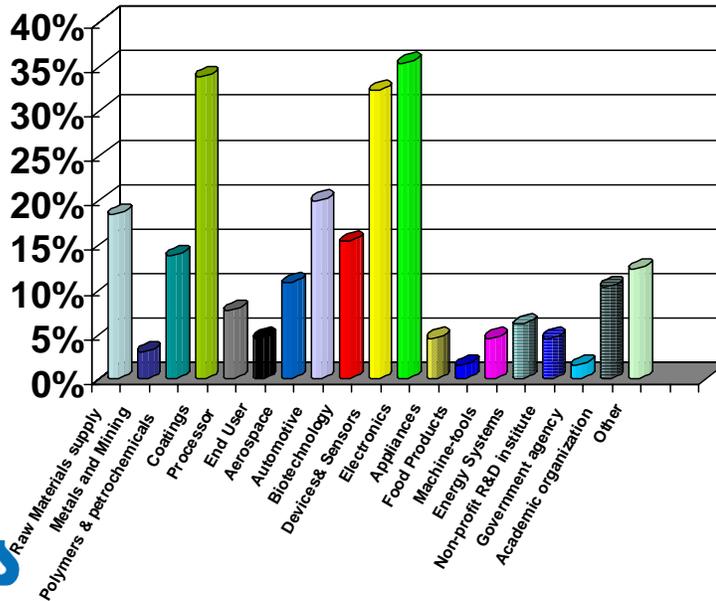
- Electronics/Semiconductors
- Coatings
- Devices/sensors
- Automotive
- Materials
- Biotech/Biomedical
- Polymers



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Nanomanufacturing Applications



Perception of Change

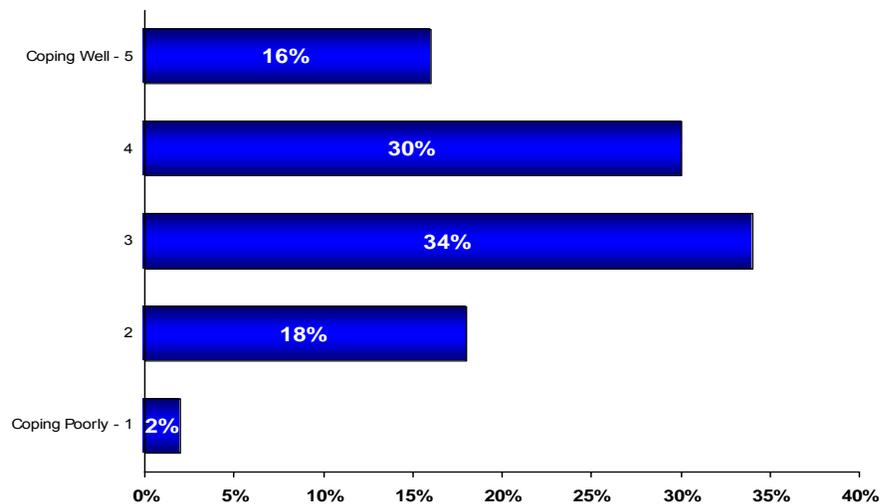
- **63%** feel their business and markets are experiencing significant change
- **82%** are dissatisfied with how their organizations are coping with change
- **> 50%** organizations have insufficient internal capacity to pursue developments in nanomanufacturing
- **75%** expressed varying degrees of inadequacy in infrastructure for nanomfg.



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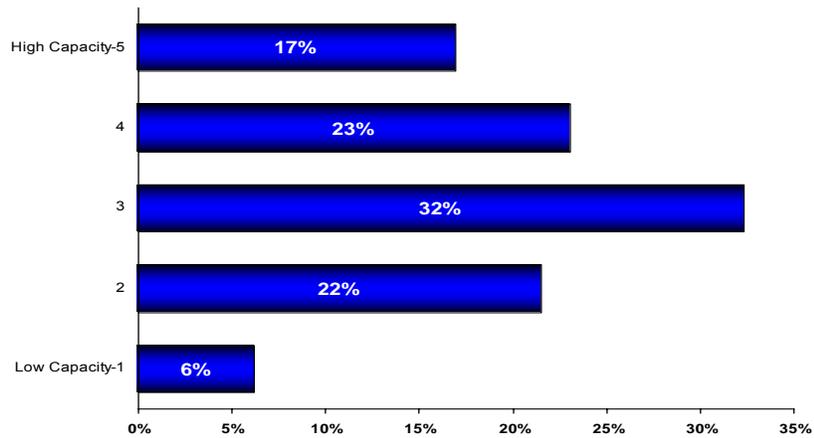
Coping with strategic change – E.g., product portfolio, investments, market-focus



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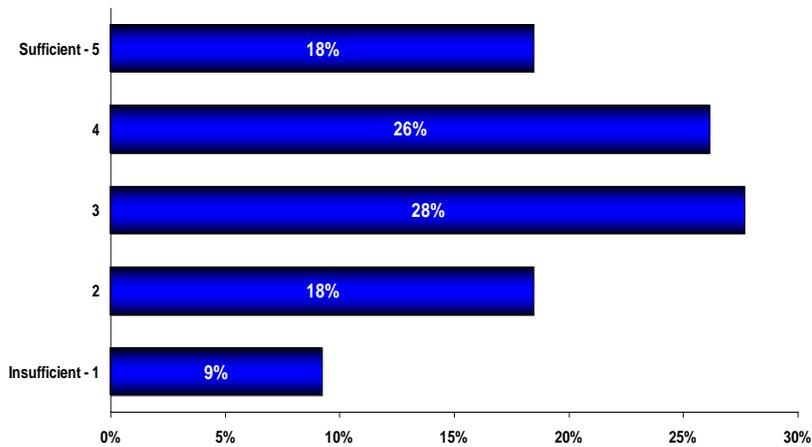
Capacity to pursue nanomanufacturing – E.g., resources, capital, manpower



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Infrastructure for nanomanufacturing – E.g. laboratory space, processing equipment, test & diagnostics



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Importance of Nanomanufacturing

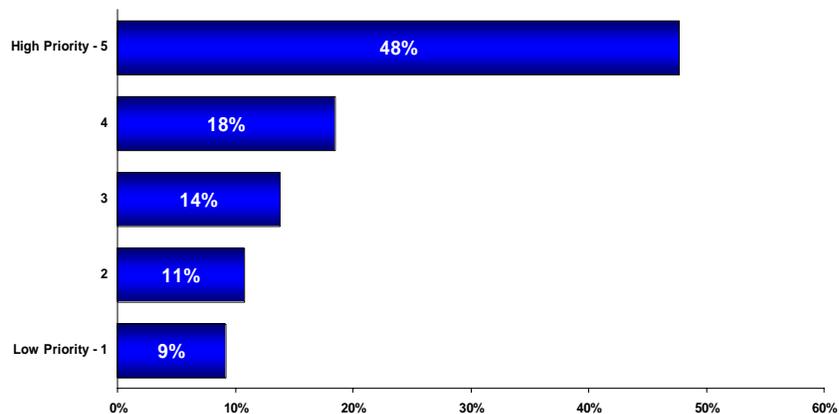
- **48% consider nanomanufacturing as an urgent area for development**
 - Small companies dominate specialty products
- **91% combine internal & collaboration**
 - IP is being co-developed
 - Resource shortfalls are addressed by leveraging
- **98% want degree of government involvement**
 - Majority favor incentives
- **> 80% employ less than 30 staff**



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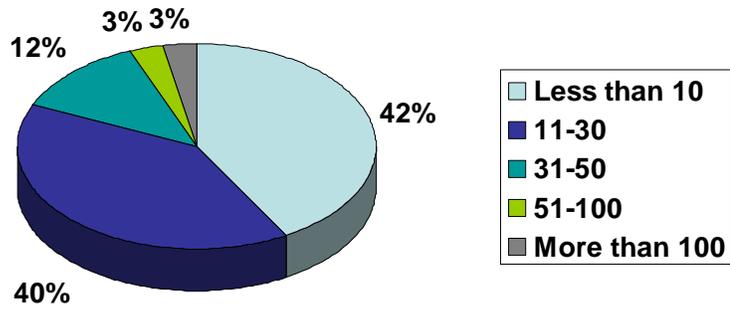
Urgency for commercialization – (Importance of U.S. leadership)



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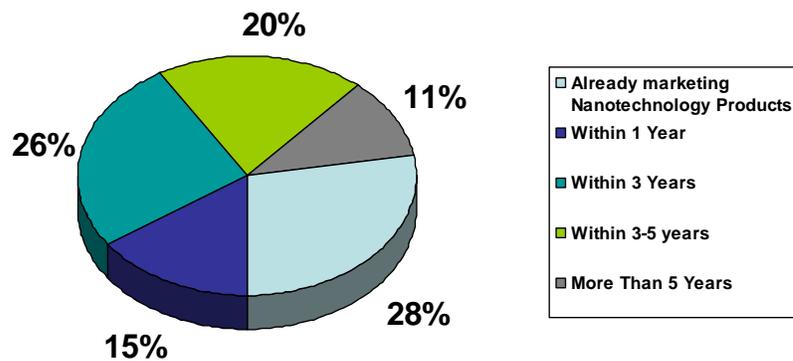
Staffing for Commercialization



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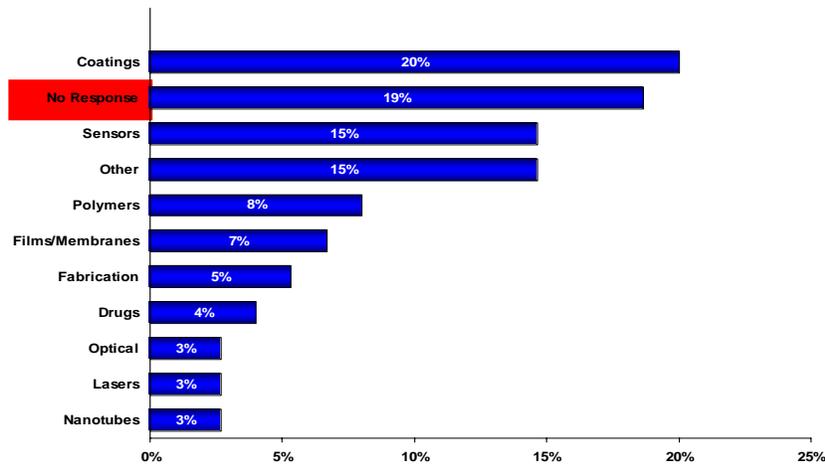
Timeline for Commercialization



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Products Being Commercialized



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Types of Nanotech Products

A wide range and functionality of nanotech products are reaching commercialization -

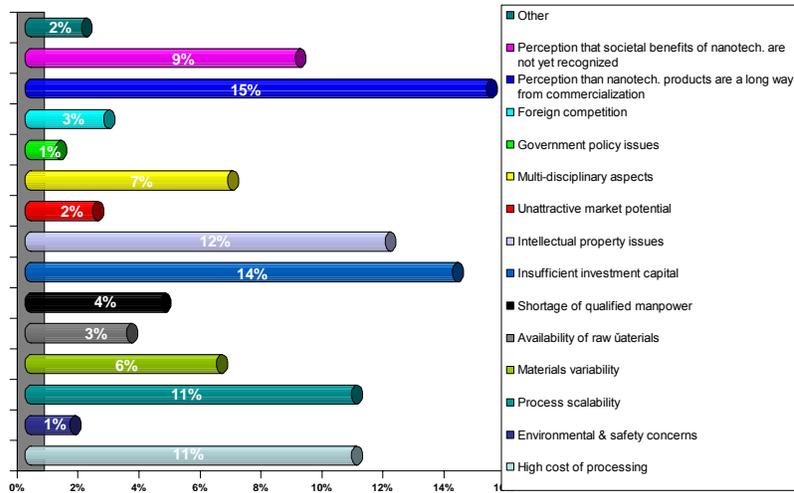
- Coatings
- Sensors
- Raw material forms
- Fabrication Processes
- Drug delivery
- 19% respondents did not divulge! (SECURITY!)



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Challenges to Industry



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Barriers to Commercialization

- Public perception that nanotech products are far from commercialization
- Insufficient investment capital
- Intellectual property issues & impediments
- Process scalability
- High cost of processing
- Societal benefits are not yet recognized



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Key Observations

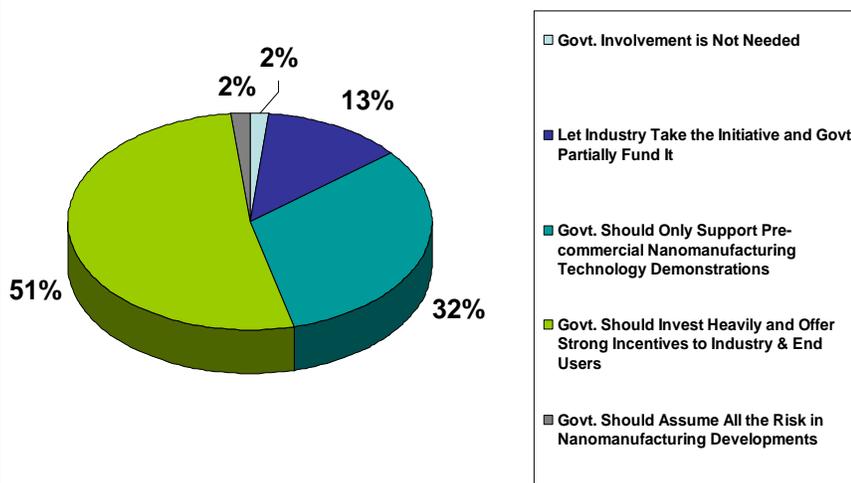
- Foreign competition is not perceived an important barrier
- Environmental & safety concerns did not rank high – other barriers are considered more critical to the industry



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Role of Government



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Other Challenges Facing the Nanomanufacturing Industry - Selected Comments by Survey Respondents

“Need much better nanofabrication and manufacturing technologies and techniques i.e., directed self-assembly, synergy of top-down and bottom-up, etc.”

“Novel high volume and 3D nanomanufacturing technology is missing.”

“Nanotechnology hype is hurting real progress. We don't need another dot.bomb cycle.”

“Lack of knowledge - we can't sell anything we can't make and we can't make anything, yet.”

“Commercialization of new products, especially those which have the potential to make disruptive advances in other fields.”

“Insufficient understanding to enable prediction of needed properties and how to achieve them.”

“Inadequate characterization capability.”

